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Markov et al.

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(54) **SYSTEM AND METHOD FOR DETECTING TRACHEA**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(Continued)

(52) **U.S. Cl.**

CPC .... ***G06V 10/457*** (2022.01); ***G06T 7/0012*** (2013.01); ***G06T 7/11*** (2017.01); (Continued)

(58) **Field of Classification Search**

CPC .... G06V 10/457; G06V 2201/031; G06T 7/0012; G06T 7/11; G06T 7/187; (Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,592,939 A	1/1997	Martinelli	
5,611,025 A	3/1997	Lorensen et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

JP	2005124895 A	5/2005
WO	2006085254 A1	8/2006

OTHER PUBLICATIONS

Australian Examination Report issued in corresponding Appl. No. AU 2015284303 dated Feb. 27, 2019 (3 pages).

(Continued)

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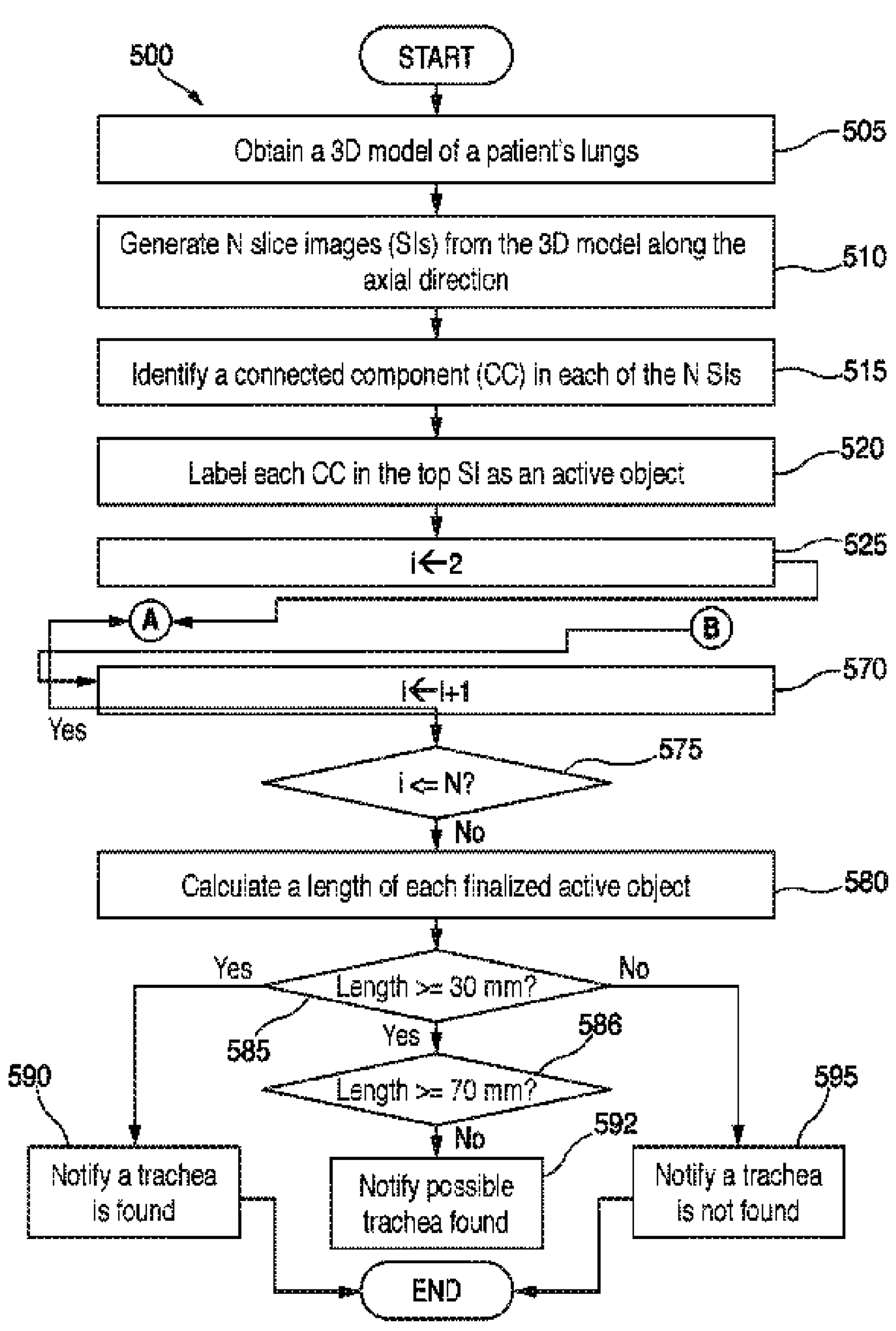
(57) **ABSTRACT**

Disclosed are systems, devices, and methods for detecting a trachea, an exemplary system comprising an imaging device configured to obtain image data and a computing device configured to generate a three-dimensional (3D) model, identify a potential connected component in a first slice image, identify a potential connected component in a second slice image, label the first slice image as a top slice image, label the connected component in the top slice image as an active object, associate each connected component in a current slice image with a corresponding connected component in a previous slice image based on a connectivity criterion, label each connected component in the current slice image associated with a connected component of the preceding slice image as the active object, and identify the active object as the trachea, based on a length of the active object.

20 Claims, 6 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/997,258, filed on Jun. 4, 2018, now Pat. No. 10,776,914, which is a continuation of application No. 15/672,612, filed on Aug. 9, 2017, now Pat. No. 9,990,721, which is a continuation of application No. 15/383,044, filed on Dec. 19, 2016, now Pat. No. 9,741,115, which is a continuation of application No. 14/755,708, filed on Jun. 30, 2015, now Pat. No. 9,530,219.

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G06T 15/20	(2011.01)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC G06T 15/205; G06T 2200/04; G06T 2200/08; G06T 2207/10081; G06T 2207/10088; G06T 2207/10104; G06T 2207/10121; G06T 2207/10132; G06T 2207/30061

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,676,673	A	10/1997	Ferre et al.	
5,682,886	A	11/1997	Delp et al.	
5,697,377	A	12/1997	Wittkampf	
5,699,799	A	12/1997	Xu et al.	
5,715,836	A	2/1998	Kliegis et al.	
5,729,129	A	3/1998	Acker	
5,752,513	A	5/1998	Acker et al.	
5,782,762	A	7/1998	Vining	
5,881,124	A	3/1999	Giger et al.	
5,891,030	A	4/1999	Johnson et al.	
5,913,820	A	6/1999	Bladen et al.	
5,920,319	A	7/1999	Vining et al.	
5,967,980	A	10/1999	Ferre et al.	
5,971,767	A	10/1999	Kaufman et al.	
5,987,960	A	11/1999	Messner et al.	
6,019,725	A	2/2000	Vesely et al.	
6,047,080	A	4/2000	Chen et al.	
6,083,162	A	7/2000	Vining	
6,138,045	A	10/2000	Kupinski et al.	
6,151,404	A	11/2000	Pieper	
6,167,296	A	12/2000	Shahidi	
6,181,348	B1	1/2001	Geiger	
6,201,387	B1	3/2001	Govari	
6,233,476	B1	5/2001	Strommer et al.	
6,246,784	B1	6/2001	Summers et al.	
6,256,400	B1 *	7/2001	Takata	G06V 40/20 382/103
6,266,551	B1	7/2001	Osadchy et al.	
6,332,089	B1	12/2001	Acker et al.	
6,346,940	B1	2/2002	Fukunaga	
6,366,800	B1	4/2002	Vining et al.	
6,381,485	B1	4/2002	Hunter et al.	
6,387,092	B1	5/2002	Burnside et al.	
6,466,815	B1	10/2002	Saito et al.	
6,496,188	B1	12/2002	Deschamps et al.	
6,501,848	B1	12/2002	Carroll et al.	
6,501,981	B1	12/2002	Schweikard et al.	
6,505,065	B1	1/2003	Yanof et al.	
6,522,907	B1	2/2003	Bladen et al.	
6,526,162	B2	2/2003	Asano et al.	
6,535,756	B1	3/2003	Simon et al.	
6,578,579	B2	6/2003	Burnside et al.	
6,584,174	B2	6/2003	Schubert et al.	
6,603,868	B1	8/2003	Ludwig et al.	
6,611,793	B1	8/2003	Burnside et al.	
6,650,927	B1	11/2003	Keidar	
6,651,669	B1	11/2003	Burnside	
6,694,163	B1	2/2004	Vining	
6,757,557	B1	6/2004	Bladen et al.	
6,783,523	B2	8/2004	Qin et al.	
6,792,390	B1	9/2004	Burnside et al.	
6,829,379	B1	12/2004	Knoplioch et al.	
6,850,794	B2	2/2005	Shahidi	
6,892,090	B2	5/2005	Verard et al.	
6,898,263	B2	5/2005	Avinash et al.	
6,909,913	B2	6/2005	Vining	
6,920,347	B2	7/2005	Simon et al.	
6,925,200	B2	8/2005	Wood et al.	
7,006,677	B2	2/2006	Manjeshwar et al.	
7,072,501	B2	7/2006	Wood et al.	
7,085,400	B1	8/2006	Holsing et al.	
7,096,148	B2	8/2006	Anderson et al.	
7,149,564	B2	12/2006	Vining et al.	
7,167,180	B1	1/2007	Shibolet	
7,174,202	B2	2/2007	Bladen et al.	
7,179,220	B2	2/2007	Kukuk	
7,236,558	B2	6/2007	Saito et al.	
7,301,332	B2	11/2007	Govari et al.	
7,308,112	B2 *	12/2007	Fujimura	G06V 40/113 382/103
7,315,639	B2	1/2008	Kuhnigk	
7,324,104	B1	1/2008	Bitter et al.	
7,336,809	B2 *	2/2008	Zeng	G06T 7/149 382/128
7,397,937	B2	7/2008	Schneider et al.	
7,428,334	B2	9/2008	Schoisswohl et al.	
7,452,357	B2	11/2008	Vlegele et al.	
7,505,809	B2	3/2009	Strommer et al.	
7,517,320	B2	4/2009	Wibowo et al.	
7,518,619	B2	4/2009	Stoval, III et al.	
7,574,031	B2 *	8/2009	Dehmeshki	G06T 7/155 378/23
7,630,752	B2	12/2009	Viswanathan	
7,630,753	B2	12/2009	Simon et al.	
7,659,912	B2	2/2010	Akimoto et al.	
7,702,153	B2	4/2010	Hong et al.	
7,751,865	B2	7/2010	Jascob et al.	
7,756,316	B2	7/2010	Odry et al.	
7,760,182	B2 *	7/2010	Ahmad	G06Q 30/00 382/209
7,788,060	B2	8/2010	Schneider	
7,792,565	B2	9/2010	Vining	
7,805,269	B2	9/2010	Glossop	
7,809,176	B2	10/2010	Gundel	
7,811,294	B2	10/2010	Strommer et al.	
7,822,461	B2	10/2010	Geiger et al.	
7,901,348	B2	3/2011	Soper et al.	
7,907,772	B2	3/2011	Wang et al.	
7,929,014	B2	4/2011	Akimoto et al.	
7,951,070	B2	5/2011	Ozaki et al.	
7,969,142	B2	6/2011	Krueger et al.	
7,985,187	B2	7/2011	Wibowo et al.	
8,009,891	B2	8/2011	de Vaan	
8,044,972	B2	10/2011	Hall	
8,049,777	B2	11/2011	Akimoto et al.	
8,055,323	B2	11/2011	Sawyer	
8,102,416	B2	1/2012	Ito et al.	
8,126,241	B2	2/2012	Zarkh et al.	
8,131,344	B2	3/2012	Strommer et al.	
8,170,328	B2	5/2012	Masumoto et al.	
8,199,981	B2	6/2012	Koptenko et al.	

(56) **References Cited**

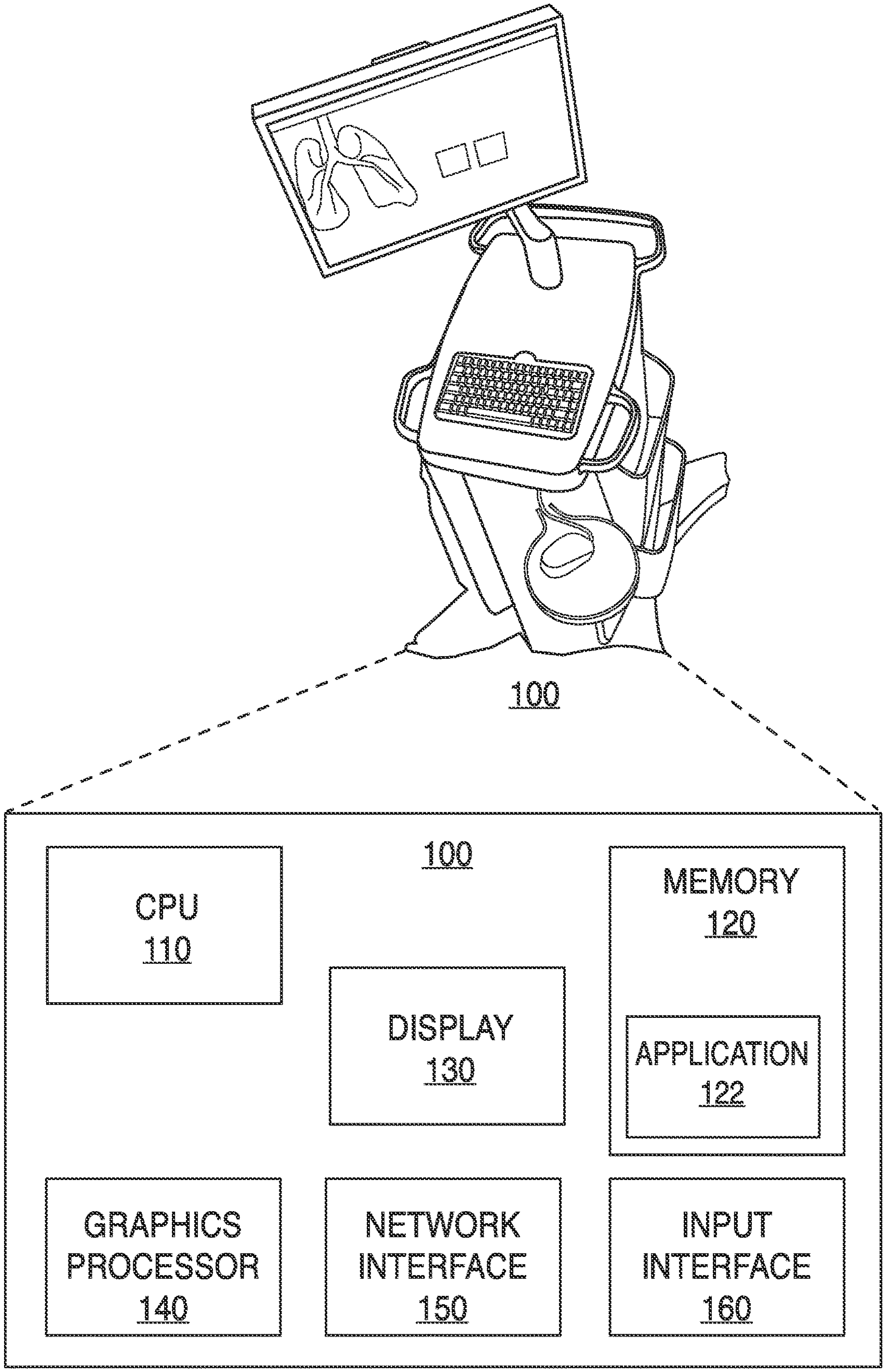
U.S. PATENT DOCUMENTS

8,200,314 B2 6/2012 Bladen et al.
8,202,213 B2 6/2012 Ito et al.
8,208,708 B2 6/2012 Homan et al.
8,219,179 B2 7/2012 Ganatra et al.
8,257,346 B2 9/2012 Qin et al.
8,267,927 B2 9/2012 Dalal et al.
8,290,228 B2 10/2012 Cohen et al.
8,298,135 B2 10/2012 To et al.
8,381,108 B2* 2/2013 Fuller A63F 13/30 715/727
8,391,952 B2 3/2013 Anderson
8,417,009 B2 4/2013 Mizuno
8,494,612 B2 7/2013 Vetter et al.
8,509,877 B2 8/2013 Mori et al.
8,672,836 B2 3/2014 Higgins et al.
8,682,045 B2 3/2014 Vining et al.
8,696,549 B2 4/2014 Holsing et al.
8,698,806 B2 4/2014 Kunert et al.
8,700,132 B2 4/2014 Ganatra et al.
8,706,193 B2 4/2014 Govari et al.
8,709,034 B2 4/2014 Keast et al.
8,730,237 B2 5/2014 Ruijters et al.
8,768,029 B2 7/2014 Helm et al.
8,784,400 B2 7/2014 Roschak
8,798,227 B2 8/2014 Tsukagoshi et al.
8,798,339 B2 8/2014 Mielekamp et al.
8,801,601 B2 8/2014 Prisco et al.
8,819,591 B2 8/2014 Wang et al.
8,819,812 B1* 8/2014 Weber G06F 3/017 726/19
8,824,802 B2* 9/2014 Kutliroff G06V 20/64 348/46
8,836,768 B1* 9/2014 Rafii G02B 27/017 348/47
8,862,204 B2 10/2014 Sobe et al.
9,141,193 B2* 9/2015 Perez G06F 3/038
9,285,872 B1* 3/2016 Raffle G06F 3/012
9,530,219 B2 12/2016 Markov et al.
9,672,631 B2* 6/2017 Higgins G06T 7/162
9,741,115 B2 8/2017 Markov et al.
9,990,721 B2 6/2018 Markov et al.
10,776,914 B2 9/2020 Markov et al.
11,361,439 B2 6/2022 Markov et al.
2003/0095696 A1* 5/2003 Reeves G06T 7/155 382/173
2004/0101183 A1* 5/2004 Mullick G06T 7/49 382/131
2005/0207630 A1* 9/2005 Chan G06T 7/0012 382/131
2005/0256611 A1* 11/2005 Pretlove G05B 19/42 700/264
2007/0092864 A1* 4/2007 Reinhardt G06T 7/11 600/300
2008/0183073 A1 7/2008 Higgins et al.
2008/0205717 A1* 8/2008 Reeves G06T 5/002 382/128
2008/0317314 A1* 12/2008 Schwartz G06T 7/0012 382/131
2009/0012390 A1 1/2009 Pescatore et al.
2009/0030306 A1 1/2009 Miyoshi et al.
2009/0080743 A1* 3/2009 Launay G06T 7/12 382/131
2009/0136103 A1 5/2009 Sonka
2009/0185731 A1* 7/2009 Ray G06T 7/12 382/131
2009/0226060 A1* 9/2009 Gering G06T 7/174 382/128
2009/0316952 A1* 12/2009 Ferren G06F 3/0425 382/103
2010/0021034 A1* 1/2010 Lenglet G06T 7/149 382/131
2010/0045705 A1* 2/2010 Vertegaal G06F 1/1613 345/173
2010/0054525 A1* 3/2010 Gong G06T 7/149 382/100
2010/0164496 A1* 7/2010 Briggs G01R 33/56366 324/309
2010/0310146 A1* 12/2010 Higgins G06T 7/162 345/419
2010/0312094 A1 12/2010 Guttman et al.
2010/0322496 A1 12/2010 Liu
2011/0093243 A1* 4/2011 Tawhai G06T 7/0012 703/2
2011/0237897 A1 9/2011 Gilboa
2011/0251607 A1 10/2011 Kruecker et al.
2012/0203065 A1 8/2012 Higgins et al.
2012/0249546 A1 10/2012 Tschirren et al.
2012/0280135 A1* 11/2012 Bal A61N 5/1039 250/336.1
2012/0287238 A1 11/2012 Onishi et al.
2013/0004016 A1* 1/2013 Karakotsios G06V 40/28 382/103
2013/0095924 A1* 4/2013 Geisner A63F 13/21 463/32
2013/0165854 A1 6/2013 Sandhu et al.
2013/0265218 A1* 10/2013 Moscarillo G06F 3/0416 345/156
2013/0271370 A1* 10/2013 Wang G06V 40/113 345/158
2013/0294651 A1* 11/2013 Zhou G06V 40/28 382/103
2014/0029828 A1* 1/2014 Schwartz G06V 10/993 382/131
2014/0184475 A1* 7/2014 Tantos H04N 21/234318 345/8
2014/0267009 A1* 9/2014 DeLean G06V 40/28 345/156
2014/0281946 A1* 9/2014 Avni H04L 63/12 726/4
2015/0012426 A1* 1/2015 Purves G02B 27/017 705/41
2016/0005163 A1 1/2016 Markov et al.
2016/0188181 A1* 6/2016 Smith G06F 3/0412 715/765
2016/0320466 A1* 11/2016 Berker G06T 7/11
2023/0060994 A1* 3/2023 Austin A61M 16/024

OTHER PUBLICATIONS

Office Action issued in corresponding Japanese Appl. No 2018-210629 dated Sep. 25, 2019, together with English language translation (14 pages).
European Search Report for Application No. 15814878.3 dated Dec. 6, 2017 (10 pages).
Ordy et al., Automated airway evaluation system for multi-slice computed tomography using airway lumen diameter, airway wall thickness and broncho-arterial ratio, Procedings Optical Diagnostics of Living Cells II, vol. 6143, Mar. 2, 2006, p. 61430Q-1-61430Q-11 (12 pages).
European Examination Report dated Nov. 2, 2018 issued in corresponding EP Appln. No. 15814878.3.

* cited by examiner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100
CPU
110
MEMORY
120
DISPLAY
130
APPLICATION
122
GRAPHICS
PROCESSOR
140
NETWORK
INTERFACE
150
INPUT
INTERFACE
160

FIG. 1

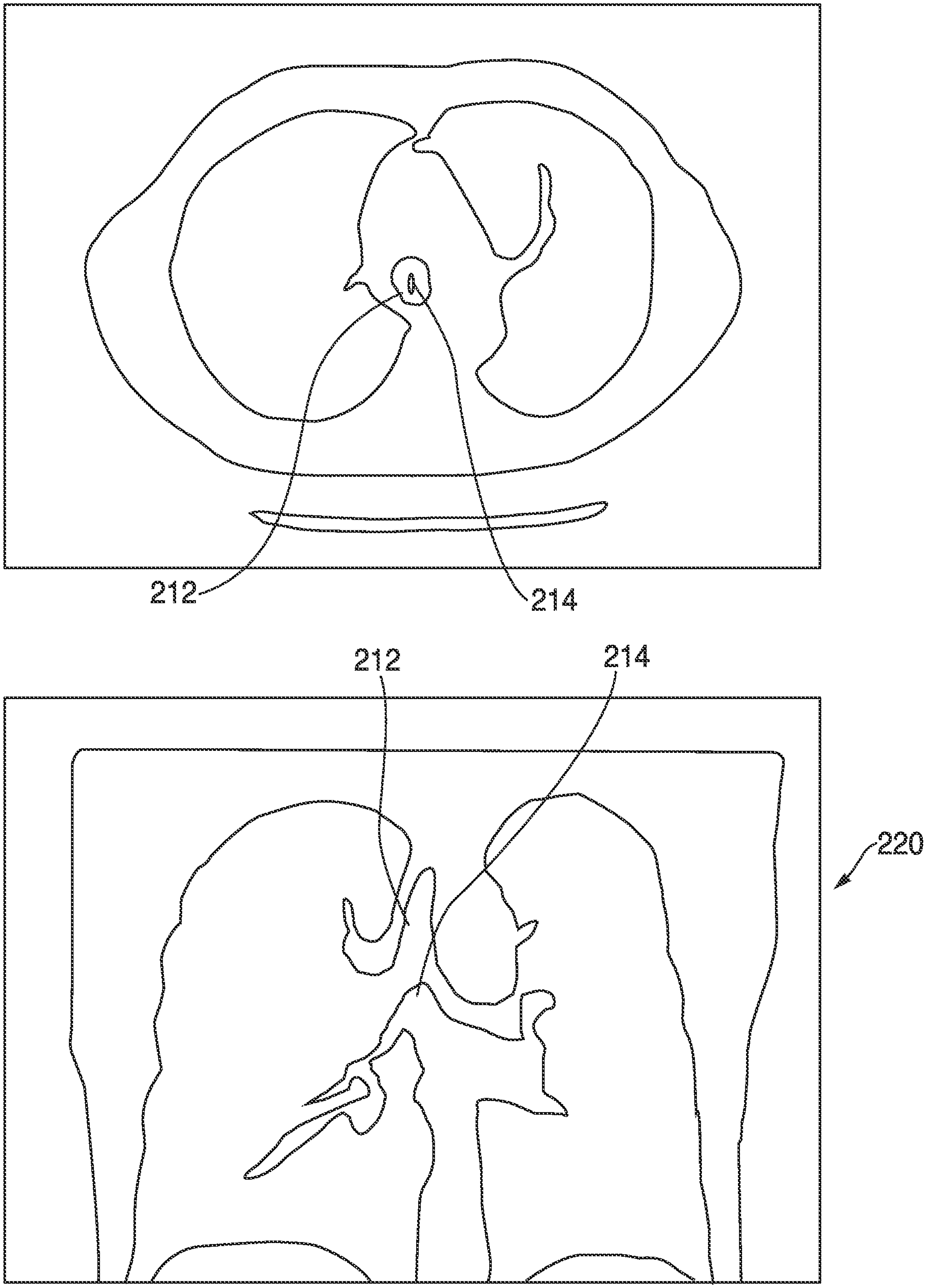

FIG. 2

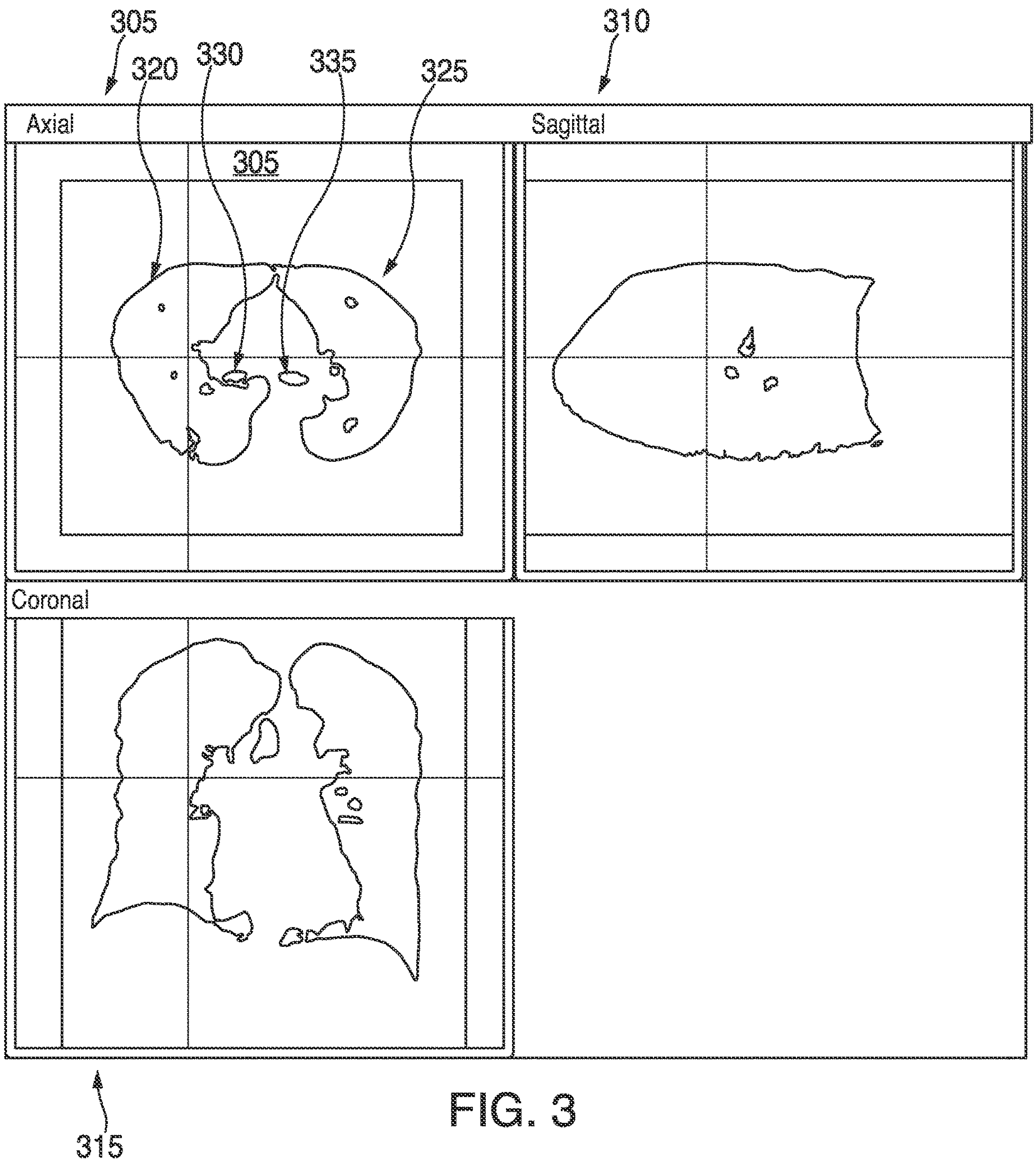

FIG. 3

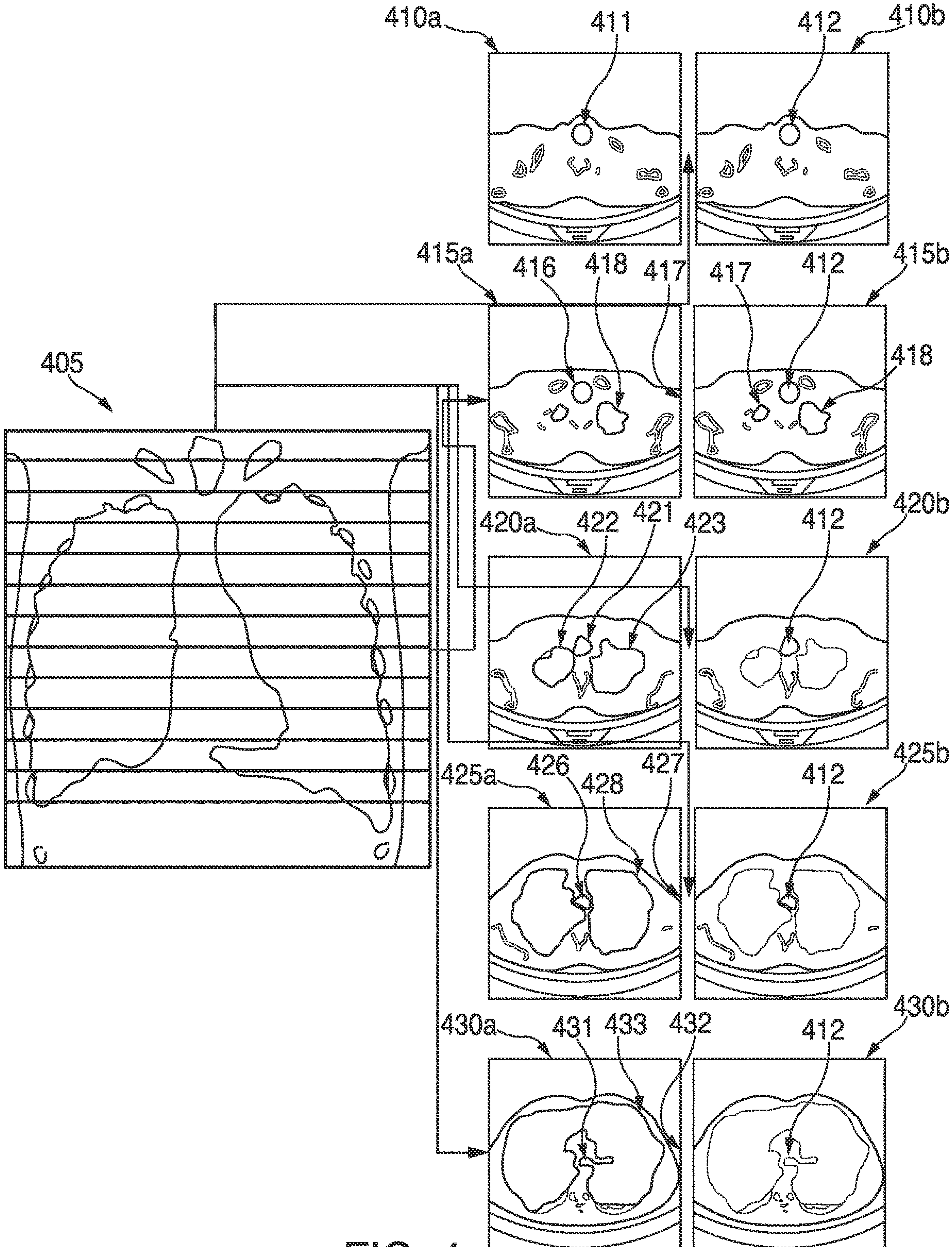
410a
411
412
410b
415a
416
418
417
417
412
415b
418
405
420a
422
421
423
412
420b
425a
426
428
427
412
425b
430a
431
433
432
412
430b

FIG. 4

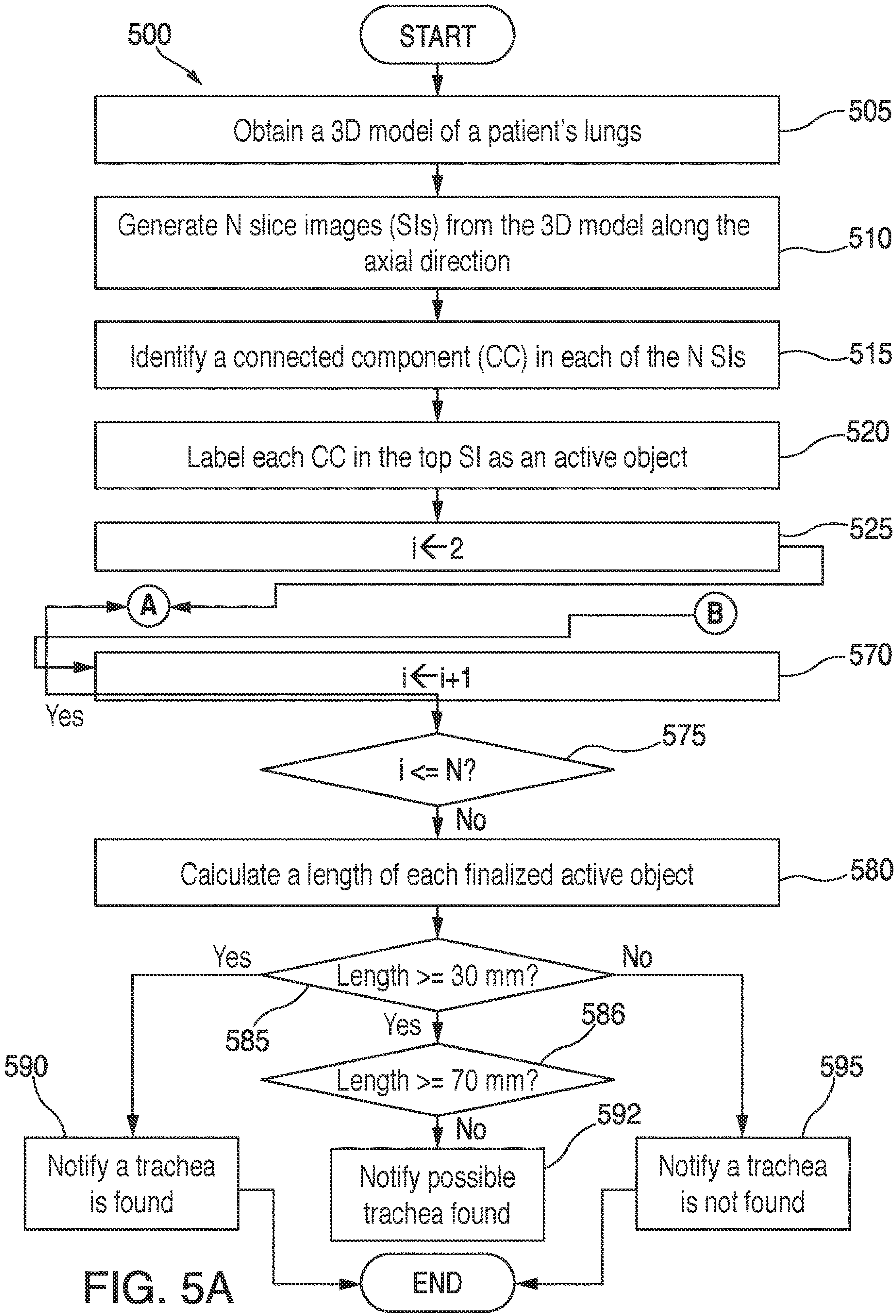
500
START
Obtain a 3D model of a patient's lungs
505
Generate N slice images (SIs) from the 3D model along the axial direction
510
Identify a connected component (CC) in each of the N SIs
515
Label each CC in the top SI as an active object
520
i←2
525
A
B
i←i+1
570
Yes
i <= N?
575
No
Calculate a length of each finalized active object
580
Yes
Length >= 30 mm?
No
585
Yes
586
Length >= 70 mm?
590
595
No
592
Notify a trachea is found
Notify possible trachea found
Notify a trachea is not found
END

FIG. 5A

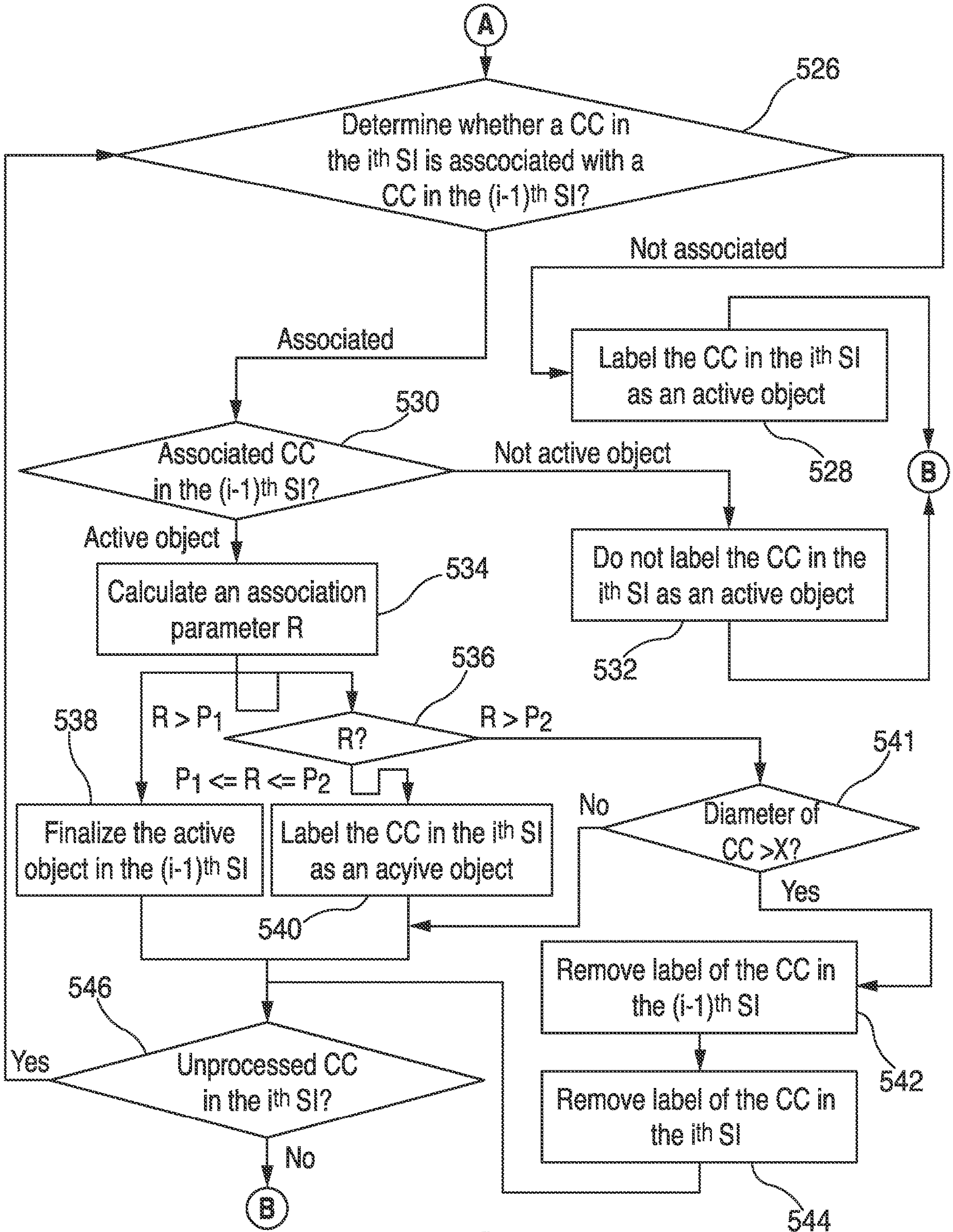
A
526
Determine whether a CC in the ith SI is asscociated with a CC in the (i-1)th SI?
Not associated
Associated
Label the CC in the ith SI as an active object
528
530
Associated CC in the (i-1)th SI?
Not active object
B
Active object
Calculate an association parameter R
534
Do not label the CC in the ith SI as an active object
532
536
R > P1
R?
R > P2
538
P1 <= R <= P2
541
No
Diameter of CC >X?
Finalize the active object in the (i-1)th SI
Label the CC in the ith SI as an acyive object
Yes
540
Remove label of the CC in the (i-1)th SI
546
542
Yes
Unprocessed CC in the ith SI?
Remove label of the CC in the ith SI
No
B
544

FIG. 5B

SYSTEM AND METHOD FOR DETECTING TRACHEA

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 17/016,695, filed on Sep. 10, 2020, which is a continuation of U.S. patent application Ser. No. 15/997,258, filed on Jun. 4, 2018, now U.S. Pat. No. 10,776,914, which is a continuation of U.S. patent application Ser. No. 15/672,612, filed on Aug. 9, 2017, now U.S. Pat. No. 9,990,721, which is a continuation of U.S. patent application Ser. No. 15/383,044, filed on Dec. 19, 2016, now U.S. Pat. No. 9,741,115, which is a continuation of U.S. patent application Ser. No. 14/755,708, filed on Jun. 30, 2015, now U.S. Pat. No. 9,530,219, which claims the benefit of and priority to U.S. Provisional Patent Application Ser. No. 62/020,257, filed on Jul. 2, 2014, the entire contents of each of which being incorporated by reference herein.

FIELD

The present disclosure relates to systems and methods for detecting a trachea. More particularly, the present disclosure relates to systems and methods that detect a trachea based on slice images of a three-dimensional volume of a chest.

BACKGROUND

Visualization techniques related to visualizing a chest have been developed so as to help clinicians perform diagnoses and/or surgeries on organs or other parts contained within the chest. Visualization is especially important for identifying a location of a diseased region. Further, when treating the diseased region, additional emphasis is given to identification of the particular location of the diseased region so that a surgical operation is performed at the correct location in the chest.

In the past, scanned two-dimensional images of the chest have been used to aid in visualization. In order to visualize a lung from scanned two-dimensional images of the chest, it is important to determine whether or not an area of the two-dimensional images is a part of the lung. Thus, detecting a starting location, for example, a location of an organ or other part that is connected to or is a part of the lung, is also important for identifying the lung. In one example, the trachea can be used as the starting location because the trachea has a substantially constant diameter along its length and is known to be connected to the lung.

SUMMARY

Provided in accordance with the present disclosure is a system for detecting a trachea of a patient.

In an aspect of the present disclosure, the system includes an imaging device configured to obtain image data of the patient, and a computing device including a processor and a memory storing instructions which, when executed by the processor, cause the computing device to generate a three-dimensional (3D) model of a chest of the patient based on the image data, generate slice images of the 3D model along an axial direction, identify a potential connected component in a first slice image of the generated slice images, identify a potential connected component in a second slice image of the generated slice images, wherein the second slice image is immediately subsequent to the first generated slice image,

confirm that the potential connected component of the first and second slice images are connected, label the potential connected component as a connected component, label the first slice image as a top slice image of the generated slice images, label the connected component in the top slice image as an active object, associate each connected component in a current slice image of the generated slice images with a corresponding connected component in a previous slice image based on a connectivity criterion, label each connected component in the current slice image associated with a connected component of the preceding slice image as the active object, and identify the active object as the trachea, based on a length of the active object.

In another aspect of the present disclosure, the image data is obtained by an imaging device using a tomographic technique, radiography, tomogram produced by a computerized axial tomography scan, magnetic resonance imaging, ultrasonography, contrast imaging, fluoroscopy, nuclear scans, or positron emission tomography.

In a further aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image.

In another aspect of the present disclosure, the slice images are spaced at an equal distance apart from each other.

In a further aspect of the present disclosure, the instructions further cause the computing device to calculate a length of a finalized active object by multiplying a number of slice images contained in the finalized active object minus one and the distance between each slice image.

In another aspect of the present disclosure, when the length of the finalized active object is greater than or equal to 70 mm, the instructions further cause the computing device to indicate that the trachea is identified.

In a further aspect of the present disclosure, when the length of the finalized active object is greater than or equal to 30 mm but less than 70 mm, the instructions further cause the computing device to indicate that the trachea is potentially identified.

In another aspect of the present disclosure, when the length of the finalized active object is less than 30 mm, the instructions further cause the computing device to indicate that the trachea is not identified.

In a further aspect of the present disclosure, a connected component of the current slice image is associated with the corresponding connected component in the previous slice image when coordinates of a pixel in the connected component of the current slice image matches coordinates of a pixel in the corresponding connected component in the previous slice image.

In another aspect of the present disclosure, a connected component of the current slice image is associated with the corresponding connected component in the previous slice image when a difference between a center of mass of the connected component of the current slice image and a center of mass of the corresponding connected component in the previous slice image is less than a predetermined value.

In a further aspect of the present disclosure, a connected component of the current slice image is associated with a corresponding connected component in the previous slice image when a difference between an area of the connected component of the current slice image and an area of the corresponding connected component in the previous slice image is less than a predetermined value.

In another aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and wherein the association parameter is an area ratio calculated by dividing an area of the connected component in the current slice image by an area of the corresponding connected component in the previous slice image.

In a further aspect of the present disclosure, wherein the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and wherein the association parameter is a ratio between a number of coordinates of the connected component of the current slice image, which match coordinates of the corresponding active object in the previous slice image, and a number of non-matching coordinates of the connected component of the current slice image

In another aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and wherein the association parameter is an area of the connected component of the current slice image.

In a further aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and remove the label of the corresponding active object of the previous slice as an active object when the association parameter is greater than a predetermined value.

In another aspect of the present disclosure, the instructions further cause the computing device to remove the label of the connected component of the current slice as an active object when the association parameter is greater than the predetermined value.

In a further aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and wherein an active object is finalized when the association parameter is less than a predetermined value.

In another aspect of the present disclosure, the instructions further cause the computing device to finalize the active object in the previous slice image based on an association parameter, and label the connected component of the current slice as the active object when the association parameter is greater than or equal to a first predetermined value and less than or equal to a second predetermined value.

Any of the above aspects and embodiments of the present disclosure may be combined without departing from the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

Objects and features of the presently disclosed systems and methods will become apparent to those of ordinary skill in the art when descriptions of various embodiments are read with reference to the accompanying drawings, of which:

FIG. **1** is a schematic diagram of an example device which may be used to detect a trachea in a 3D model of a patient's lungs, in accordance with an embodiment of the present disclosure;

FIG. **2** depicts 2D slice images generated from the 3D model showing the trachea in the axial and coronal orientations, in accordance with embodiments of the present disclosure;

FIG. **3** is a graphical illustration of connected components in 2D slice images of a a patient's chest in accordance with embodiments of the present disclosure;

FIG. **4** is a graphical illustration of a planar view of 2D slice images of the patient's chest in accordance with embodiments of the present disclosure;

FIG. **5**A is a flowchart of a method for detecting a trachea in accordance with embodiments of the present disclosure; and

FIG. **5**B is a flowchart of a method for determining an association between 2D slice images in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is related to systems and methods for automatically detecting a trachea based on 2D slice images of a patient's chest. Identifying the trachea may be a necessary component of pathway planning for performing an ELECTROMAGNETIC NAVIGATION BRONCHOSCOPY® (ENB) procedure using an electromagnetic navigation (EMN) system.

An ENB procedure generally involves at least two phases: (1) planning a pathway to a target located within, or adjacent to, the patient's lungs; and (2) navigating a probe to the target along the planned pathway. These phases are generally referred to as (1) "planning" and (2) "navigation." By detecting the trachea, the lung can be visually distinguished from areas outside of the lung because the lung is connected to the trachea. An example of the planning software described herein can be found in U.S. Pat. Nos. 9,459,770, 9,925,009, and 9,639,666, all of which were filed by Covidien LP on Mar. 15, 2013, and entitled "Pathway Planning System and Method," all of which are incorporated herein by reference. An example of the planning software can be found in commonly assigned U.S. Pat. No. 9,770,216 entitled "SYSTEM AND METHOD FOR NAVIGATING WITHIN THE LUNG" the entire contents of which are incorporated herein by reference.

Prior to the planning phase, the patient's lungs are imaged by, for example, a computed tomography (CT) scan, although additional applicable methods of imaging will be known to those skilled in the art. The image data assembled during the CT scan may then be stored in, for example, the Digital Imaging and Communications in Medicine (DICOM) format, although additional applicable formats will be known to those skilled in the art. The CT scan image data may then be loaded into a planning software application ("application") to be processed for generating a 3D model which may be used during the planning phase of the ENB procedure.

The application may use the CT scan image data to generate a 3D model of the patient's lungs. The 3D model may include, among other things, a model airway tree corresponding to the actual airways of the patient's lungs, and showing the various passages, branches, and bifurcations of the patient's actual airway tree. While the CT scan image data may have gaps, omissions, and/or other imperfections included in the image data, the 3D model is a smooth representation of the patient's airways, with any such gaps, omissions, and/or imperfections in the CT scan image data filled in or corrected.

The planning phase generally involves identifying at least one target in the 3D model, and generating a pathway to the target. The pathway will generally run from the patient's mouth, through the trachea and connected airways, to the target. However, in order to generate the pathway to the target, the location of the trachea within the 3D model must be known.

As described in more detail below, the application will attempt to automatically detect the trachea within the 3D model. However, there may be instances where automatic detection of the trachea fails. In such instances, the trachea may need to be manually identified and marked. This process is more fully described in commonly-owned U.S. Pat. No. 9,754,367 entitled "Trachea Marking", filed on Jul. 2, 2014, by Lachmanovich et al., the entire contents of which are hereby incorporated by reference.

The trachea provides a passage way for breathing. The trachea is connected to the larynx and the pharynx in the upper end. In particular, the upper part of the trachea extends substantially linearly from the larynx and pharynx and behind the sternum. The lower end of the trachea branches into a pair of smaller tubes, i.e., primary bronchi, each tube connecting to a lung. The main carina is a cartilaginous ridge formed by the branching of the trachea into the primary bronchi. The diameter of the trachea is substantially constant along its length (i.e., the axial direction), while the size of the lung changes substantially along the same direction as the length of the trachea. Thus, by analyzing 2D slice images of the 3D model, the trachea may be detected.

FIG. **1** shows an image processing device **100** that may be used during the planning phase of an ENB procedure to detect the location of the trachea in the 3D model. Device **100** may be a specialized image processing computer configured to perform the functions described below. Device **100** may be embodied in any form factor known to those skilled in the art, such as, a laptop, desktop, tablet, or other similar computer. Device **100** may include, among other things, one or more processors **110**, memory **120** storing, among other things, the above-referenced application **122**, a display **130**, one or more specialized graphics processors **140**, a network interface **150**, and one or more input interfaces **160**. As noted above, 2D slice images of the 3D model may be displayed in various orientations. As an example, FIG. **2** shows 2D slice images of the 3D model of the patient's lungs in the axial and coronal orientations, with 2D slice image **210** generated along the axial plane and 2D slice image **220** generated along the coronal plane.

Both 2D slice images **210** and **220** show the trachea **212** and the main carina **214**. The 2D slice images of the 3D model may show a high density area with high intensity and a low density area with low intensity. For example, bones, muscles, blood vessels, or cancerous portions are displayed with higher intensity than an inside area of airways of the lung.

In an aspect, the 2D slice images may be generated to depict the axial, coronal, and sagittal views of the patient at a given location. For example, at each intersecting point of the 3D model, there may be three different 2D slice images generated in the three independent directions. These 2D slice images may be reformatted for display. For example, application **122** may convert a color space of the 2D slice images to another color space suitable for display and perform imaging processes, e.g., scale, rotation, translation, or projection, to display the 2D slice images as intended.

The 2D slice images may be binarized by using a region growing algorithm. Based on the region growing algorithm and starting with a seed pixel, every pixel in the 2D slice images of the 3D model is checked to determine whether a Hounsfield value assigned to each pixel is less than a threshold value and whether each pixel is connected to the seed pixel. When it is determined that a value assigned to a pixel has a Hounsfield value less than the threshold value and is connected to the seed pixel, the Hounsfield value of the pixel is set to one or the maximum value. Otherwise, the Hounsfield value of the pixel is set to zero or the minimum value. As part of the region growing algorithm, the threshold is selected with a high enough value to cause leakage in the lung, and thus fill the lungs with intensity values leaked from the airways.

After every pixel in the 2D slice images of the 3D model is set to the maximum or minimum value, the 2D slice images will have only 2 colors of pixels. The result is a set of 2D slice images where the pixels having the maximum Hounsfield value would appear white, and the pixels having the minimum Hounsfield value would appear black. In some instances, the values of pixels in the 2D slice images of the 3D model are inversed so that the lung regions are shown in black and the non-lung regions are shown in white or another color. The binarized 2D slice images may show white regions as non-lung areas (e.g., bones, stomach, heart, blood vessels, walls of airways, etc.) and black regions as lung areas (e.g., the lung, the trachea, and connected components). As described in more detail below, connected components are areas of a 2D slice image which are identified as having corresponding areas in one or more of the other 2D slice images, and thus may represent the patient's lungs or trachea.

FIG. **3** illustrates three 2D slice images generated based on the 3D model in accordance with an embodiment of the present disclosure. Image **305** is generated along the axial direction, image **310** is generated along the sagittal direction, and image **315** is generated along the coronal direction. Black areas shown in the three images **305**, **310**, and **315** are lung regions, and white areas included in the three images **305**, **310**, and **315** are non-lung areas. The white areas may represent blood vessels and walls of airways. In a case where an interior area of connected components is sufficiently large and has a lower density (e.g., blood, air, or coarse space) than tissue making up the lung regions, a black area also appears. In this sense, the connected components include a lung area as well. For example, connected components in the image **305** are the left lung **320**, the right lung **325**, the left primary bronchus **330**, and the right primary bronchus **335**. White areas inside the left lung **320** and the right lung **325** are not connected components but are blood vessels or walls of airways.

The upper part of the trachea extends substantially linearly from the larynx and pharynx and behind the sternum or breastbone. The lower end of the trachea branches into a pair of smaller tubes, i.e., primary bronchi, each tube connecting to a lung. The diameter of the trachea is substantially constant along its length (i.e., the axial direction), while the size of the lung changes substantially along the same direction as the length of the trachea. Thus, by analyzing areas of connected components in each 2D slice image generated based on the 3D model, the trachea may be detected. For this reason, images generated along the axial direction may be analyzed to detect the trachea in this present disclosure. In other embodiments, images generated along the other two directions may also be used to detect the trachea.

FIG. **4** shows 2D slice images generated from the 3D model in accordance with embodiments of the present disclosure. Image **405** is a coronal image of the patient depicting the axial locations along the patient at which axial images **410***a*-**430***b* are identified and processed in accordance with the present disclosure. For example, image **410***a* is taken from an axial position along the chest indicated by the top gray line, image **415***a* is taken from another axial position along the chest indicated by the second gray line, image **420***a* is taken from another axial position along the chest indicated by the third gray line, etc.

The axial locations of the images **410**a-**430**b may be spaced an equal distance from each other, meaning that a distance between any two neighboring 2D slice images is the same distance D. The axial 2D slice images **410**a, **415**a, **420**a, **425**a, and **430**a depict a portion of the chest of the patient at different locations. As a result of the binarization, each of these images **410**a, **415**a, **420**a, **425**a, and **430**a show black enclosed areas which represent the trachea and or the lung tissue.

A process for detecting the trachea may be based on the identified connected components in each axial 2D slice image **410**a, **415**a, **420**a, **425**a, and **430**a. Generally, a first axial 2D slice image is analyzed to identify one or more identified areas which satisfy the binarization criteria (i.e., are likely either trachea or lung). In addition to identifying areas of the axial 2D slice image which satisfy the binarization criteria, an initial connected component analysis is done which filters out any portion of the axial 2D slice image **410**a that connects to the picture borders. Further, connected components which are above or below a certain size threshold are also filtered out. The remaining connected components of any one axial image slice, e.g. **410**a, is associated with an active object depending on a connectivity criteria with the connected components in other images. An axial connected component analysis is undertaken in which a determination is made as to whether connected components in two successive axial 2D slice images geographically overlap with one another. Geographical overlap can be determined by comparing coordinates of the active object in the successive images and determining if the same coordinates (e.g. X and Y coordinates) appear in the active objects of successive images. If so, the connected components from the two axial 2D slice images are associated with each other and are both correspondingly labeled as an active object. A connected component labeled as the active object is a candidate to be identified as the trachea. When the additional connected components do not geographically overlap with the one or more connected components from the previous 2D slice image, the additional connected components are labeled as a new active object. Further, if in a subsequent axial slice it is determined that there are no connected components objects which overlap with the preceding image, the active object last identified in the preceding image is finalized. The above-described steps are performed on each 2D slice image until each connected component in each coronal 2D slice image is identified and, where appropriate, classified as an active object.

The details of the process described above are further clarified with reference to FIG. **4**. In an embodiment, the top axial 2D slice image **410**a is processed first to identify or label the connected component **411**. In one embodiment, any connected component in the top axial 2D slice image **410**a is labeled as an active object. As a result, in image **410**b of the filtering described above, a single active object **412** is shown.

Next, the second axial 2D slice image **415**a is processed in a similar manner as coronal 2D slice image **410**a to identify three connected components **416**, **417**, and **418**. Again, the filtering described above is undertaken, resulting in the identification of three active objects **416**, **417**, and **418** depicted in image **415**b. A determination is made as to whether one or more of the connected components **416**-**418** geographically overlap with connected components (e.g., **411**) in the previous axial 2D slice image. As a result of this analysis, active objects **413** and **414** are new active objects, with no connected component to compare with in the preceding axial 2D slice image **410**b. However, connected component **416** geographically overlaps with and is associated with the connected component **411** in the 2D slice image **410**a, thus, connecting the two connected components **416** and **411** vertically (i.e. from axial slice to axial slice) to each other. As a result the associated connected components **416** and **411** share a common active object label **412**

With reference to a third axial 2D slice image **420**a, three connected components **421**-**423** are identified. Following the filtering described above, each connected component **421**-**423** is separately compared with the connected components **416**-**418** of the second axial 2D slice image **415**a. The connected component **421** geographically overlaps with the connected component **416**, and has a similar size or area with that of the connected component **416**. Thus, the connected component **421** is associated with the connected component **416** and labeled as the same active object **412** as the connected component **416**, which was based on its comparison to connected component **411** in axial image slice **410**a.

The connected components **422** and **423** geographically overlap with the connected components **417** and **418**, respectively and are thus candidates to be labeled as active objects **413** and **414** based on this overlap. The connected components **422** and **423**, however, must also be filtered by size, as described above. Because the areas of the connected components **422** and **423** are larger than a predetermined maximum size they must be filtered out of consideration as an active object. In FIG. **420**b, these connected components are shown as filtered out based on the change of color from black to white. In contrast, connected component **421**, which is associated with active object **412** remains black. In the context of the present disclosure, because the trachea is known to have a substantially consistent diameter along its length, and because that diameter is generally within a well known range of between about 27 and 13 mm for men, and between about 23-10 mm in women, when a connected component is identified as having a substantially larger area than an area of the corresponding connected component in the previous 2D slice image, an organ represented by such connected component is determined to be something other than the trachea and thus excluded from the analysis. As an alternative or additional step, because the connected components **422** and **423** have areas that are larger than those of connected components **416** and **418**, the connected components **422** and **423** may also be considered too large and thus not part of the trachea. Further, the connected components **417** and **418** of the second axial 2D slice image **415**b may be re-labeled to remove the active object designation. Consequently, the 2D slice images **410**b, **415**b and **420**b have only one active object **412**.

As described briefly above, a connected component of separate 2D slice images may be associated with a connected component of an adjacent upper 2D slice image based on connectivity criteria. The connectivity criteria may include consideration of equality of coordinates on the current 2D slice image with coordinates of the adjacent upper 2D slice image. In an embodiment, the coordinates of a pixel of a 2D slice image may be based on the Cartesian coordinate system, where the origin may be located in an upper left corner of the 2D slice image and coordinates increase from left to the right and from top to bottom. Alternatively, the coordinates of a pixel may be based on another coordinate system, such as polar coordinate system, which is suitable for intended purposes.

The geometric overlap between two connected components, also called an association parameter, from two different images may be calculated may be based on the number of pixels of a connected component of the current 2D slice image which match coordinates of pixels of a connected component of the adjacent upper 2D slice image. Alternatively the overlap may be assessed based on a center of mass. That is, when a center of mass of a connected component of the current 2D slice image is similar to that of a connected component of the adjacent upper 2D slice image, the connected component of the current 2D slice image is associated with the connected component of the adjacent upper 2D slice image. The center of mass may be calculated with an equal weight to every pixel in a connected component as follows:

$$C_x = \frac{\sum_{i=1}^{N} x_i}{N} \text{ and } C_y = \frac{\sum_{i=1}^{N} y_i}{N},$$

where C_x and C_y are x-axis and y-axis coordinates of the center of mass, respectively, x_i and y_i are coordinates of the i-th pixel of a connected component, and N is the total number of pixels contained in the connected component.

In another aspect, the connectivity criteria may be based on an area ratio. In particular, a ratio of an area of a non-overlapping portion of a connected component of the current 2D slice image to an area of an overlapping area of the connected component of the current slice may be compared with a first predetermined value. For example, the ratio may be computed by dividing an area of an overlapping portion of a connected component of the adjacent upper 2D slice image by an area of a non-overlapping portion of the connected component of the adjacent upper 2D slice image. When the ratio is less than the first predetermined value, the connected component of the current 2D slice image and the corresponding connected component of the adjacent upper 2D slice image are associated.

Returning to FIG. **4**, a fourth axial 2D slice image **425***a* is taken along the axial direction where three connected components **426-428** are detected. Using the connectivity criteria and filtering techniques described above, the connected component **426** is associated with the connected component **421**, the connected component **427** is associated with connected component **422**, and the connected component **428** is associated with the connected component **423**. Since the connected components **422** and **423** were previously filtered out as being tool larger and not given the label active object, the connected components **427** and **428** are also filtered out and not designated as active objects in FIG. **425***b*. The connected component **426**, however, is associated with the connected component **421**, and is ultimately labeled as part of active object **412**, as shown in the image **425***b*.

Axial 2D slice image **430***a* is the fifth 2D slice image from the top 2D slice image **410***a*. Again, three connected components **431-433** are detected in the 2D slice image **430***a*. Based on the connectivity criteria and the filtering processes described above, the connected component **431** is associated with the connected component **426**, the connected component **432** is associated with connected component **427**, and the connected component **433** is associated with the connected component **428**. As in image **425***b*, because the connected components **427** and **428** are too larger to be labeled as active objects, the connected components **432** and **433** are likewise not associated with an active objects and are removed from the analysis. The connected component **431** however, is associated with the connected component **426** is, which has previously been associated with active object **412** as shown in the image **430***b*.

As shown in the 2D slice images **430***a* and **430***b*, the area of the connected component **431** is small compared to the area of the connected component **426** in the 2D slice image **425***a*, the connected component **421** in the 2D slice image **420***a*, the connected component **416** in the 2D slice image **415***a*, and the connected component **411** in the 2D slice image **410***a*, all of which are associated with the active object **412**. In at least one embodiment because the ratio of the area of the connected component **431** to the area of the connected component **426** of the 2D slice image **425***a* is below a threshold, the active object **412** including the connected components **411**, **416**, **421**, **426**, and **431** may be finalized, meaning that the active object **412** is closed. After the active object is finalized, no other connected components are associated with the active object.

When the active object **412** is finalized, the length of the active object may be calculated by multiplying the number of 2D slice images containing the active object by the distance between adjacent 2D slice images. Based on the length of the active object, a determination is made as to whether the active object is the trachea. In an aspect, if the length of the active object is greater than 70 millimeters (mm), the active object is identified as the trachea. In another aspect, if the length of the active object is greater than or equal to 30 mm and less than or equal to 70 mm, the active object is identified as the trachea. When the length of the active object is less than 30 mm, the active object is not identified as the trachea.

FIGS. **5**A and **5**B are flowcharts of a method **500** for automatically detecting a trachea in accordance with an embodiment of the present disclosure. The method **500** starts at step **505**, in which a 3D model of a patient's lungs is generated. The 3D model may be based on CT scan image data obtained during a CT scan of the patient's chest and stored in the DICOM image format. In an aspect, the imaging modality may also be radiography, tomogram produced by a CAT scan, MRI, ultrasonography, contrast imaging, fluoroscopy, nuclear scans, and PET.

In step **510**, 2D slice images may be generated from the 3D model. The generated 2D slice images may be binarized 2D slice images including only include black and white pixels. The 2D slice images may be generated along the axial direction. Alternatively, the 2D slice images are generated along a direction other than the axial direction. In an aspect, the 2D slice images are generated at an equal distance apart so that a distance between any two 2D slice images may be easily calculated. In another aspect, the 2D slice images may be generated at different distances but may include distance information indicating how far apart each 2D slice image is from the top 2D slice image.

In step **515**, a connected component is identified in the 2D slice images. As noted above, connected components are enclosed regions in each image, with only one color pixels (e.g., black as shown in FIG. **4**). Any connected component identified in the top 2D slice image is labeled as an active object in step **520**. Active objects are considered as candidates for the trachea. In step **525**, a counter i is set to two, and the next 2D slice image is examined.

FIG. **5**B shows a flowchart for associating and labeling connected components as a part of the method **500** for automatically detecting a trachea. In step **526**, a determination is made as to whether a connected component in the ith 2D slice image is associated with a connected component in the (i−1)th 2D slice image. In an aspect, a connected component in a current 2D slice image may be associated with a connected component in the previous 2D slice image based on a location of the connected component of each of the current and previous 2D slice images. When the connected components overlap, they are associated with each other. Otherwise, the connected components are not associated.

When a determination is made that a connected component in the current 2D slice image (i.e., ith 2D slice image) is not associated with a connected component in the previous 2D slice image (i.e., (i−1)th 2D slice image), the connected component of the current 2D slice image is labeled as an active object in step **528**. Step **570** (FIG. **5**A) is then performed.

When a determination is made that a connected component in the current 2D slice image is associated with a connected component in the previous 2D slice image in step **526**, another determination is made as to whether the connected component of the previous 2D slice image is an active in step **530**. After the labeling process, step **570** of FIG. **5**A follows.

In a case where the connected component of the previous 2D slice image is labeled as an active object, an association parameter R is calculated between the connected components of the current 2D slice image and the previous 2D slice image in step **534**. The association parameter is based on connectivity criteria, which is used to determine whether two connected components of neighboring 2D slice images are closely related.

In an aspect, the association parameter is an area ratio, which is a ratio of an area of a connected component of the current 2D slice image to an area of the corresponding connected component of the previous 2D slice image. In step **536**, the association parameter is compared with two predetermined values. In a case where the association parameter R is less than a first predetermined value P_1, the connected component, which is labeled as the active object, of the previous 2D slice image is finalized in step **538**. This case occurs when the area of the connected component of the current 2D slice image decreases significantly or is completely missing. For example, since the lower end of the trachea branches out, an image of the bottom of the trachea may show a connected component, an area of which is much smaller than a cross-sectional area of the trachea. The significant decrease in the area of a connected component may indicate that the bottom of a trachea is reached.

When the association parameter R is greater than or equal to the first predetermined value P_1 but less than or equal to a second predetermined value P_2, the connected component of the current 2D slice image is labeled as the active object in step **540**. In this case, the connected component of the current 2D slice image is considered a continuation of the active object identified in the preceding 2D slice images (e.g., a trachea candidate).

When the association parameter R is greater than the second predetermined value P_2, the label of the connected component of the previous 2D slice image may be removed such that it is not labeled as an active object in step **542**. This occurs when the area of the connected component of the current 2D slice image increases significantly. As a result, the association parameter may reach 100%. In such instances a second inquiry is made at step **541** as to whether the diameter of the connected component of the current image slice is greater than a predetermined threshold, for example 30 mm for a man and 25 mm for a woman. Such a diameter of connected component would indicate that connected component cannot be the trachea. Thus, the connected component of the previous 2D slice image is not considered as a trachea. In step **544**, the label of the connected component of the current 2D slice image is also removed such that it is not labeled as an active object.

After steps **538**, **540**, and **544**, a determination is made as to whether there is an unprocessed connected component in the current 2D slice image. When a determination is made that an unprocessed connected component exists, steps **526**-**546** are repeated until no additional unprocessed connected components are found in the current 2D slice image. When a determination is made that there are no more unprocessed connected components in the current 2D slice image, step **570** of FIG. **5**A follows.

Turning now to FIG. **5**A, the counter i is increased by one in step **570**. In step **575**, the counter i is compared with the number of 2D slice images, N. When the counter i is less than or equal to the number of 2D slice images, N, the method reiterates at step **526** illustrated in FIG. **5**A. Otherwise, all connected components in each 2D slice image are processed. In step **580**, a length of the active object is calculated.

In steps **585** and **586**, the length of the active object is compared with a predetermined range of values. At step **590**, if the length of the active object is larger than the predetermined values, it is determined to be the trachea. Similarly, at step **592**, if the length of the active object is within the predetermined range, it is labeled as potentially being the trachea, and a clinician may have to confirm this before the next step of the ENB procedure can be undertaken. At step **595**, if the active objects are smaller than the predetermined range, automatic detection of the trachea fails, and manual identification and marking of the trachea is necessary. In an aspect, the predetermined range is 30 mm to 70 mm. Thus, if the length of an active object is more than 70 mm, it is determined to be the trachea, and if the length of an active object is between 30 mm and 70 mm, it is labeled as potentially being the trachea. In this way, the method **500** automatically detects a trachea from the 2D slice images.

Returning now to FIG. **1**, memory **120** includes application **122** such as EMN planning and procedure software and other data that may be executed by processors **110**. For example, the data may be the CT scan image data stored in the DICOM format and/or the 3D model generated based on the CT scan image data. Memory **120** may also store other related data, such as medical records of the patient, prescriptions and/or a disease history of the patient. Memory **120** may be one or more solid-state storage devices, flash memory chips, mass storages, tape drives, or any computer-readable storage media which are connected to a processor through a storage controller and a communications bus. Computer readable storage media include non-transitory, volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules or other data. For example, computer-readable storage media includes random access memory (RAM), read-only memory (ROM), erasable programmable read only memory (EPROM), electrically erasable programmable read only memory (EEPROM), flash memory or other solid state memory technology, CD-ROM, DVD or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store desired information and which can be accessed by device **100**.

Display **130** may be touch-sensitive and/or voice-activated, enabling display **130** to serve as both an input device and an output device.

Graphics processors **140** may be specialized graphics processors which perform image-processing functions, such as processing the CT scan image data to generate the 3D model, and process the 3D model to generate the 2D slice images of the 3D model in the various orientations as described above, as well as the 3D renderings of the 3D model. Graphics processors **140** may further be configured to generate a graphical user interface (GUI) to be displayed on display **130**. The GUI may include views showing the 2D image slices, the 3D rendering, among other things. In embodiments, graphics processors **140** may be specialized graphics processors, such as a dedicated graphics processing unit (GPU), which performs only the image processing functions so that the one or more general processors **110** may be available for other functions. The specialized GPU may be a stand-alone dedicated graphics card, or an integrated graphics card.

Network interface **150** enables device **100** to communicate with other devices through a wired and/or wireless network connection. In an embodiment, device **100** may receive the CT scan image data from an imaging device via a network connection. In other embodiments, device **100** may receive the CT scan image data via a storage device, such as a disk or other external storage media known to those skilled in the art.

Input interface **160** is used for inputting data or control information, such as setting values, text information, and/or controlling device **100**. Input interface **160** may include a keyboard, mouse, touch sensor, camera, microphone, or other data input devices or sensors used for user interaction known to those skilled in the art.

Further aspects of image and data generation, management, and manipulation useable in either the planning or navigation phases of an ENB procedure are more fully described in commonly-owned U.S. Provisional Patent Application Ser. No. 62/020,220 entitled "Real-Time Automatic Registration Feedback", filed on Jul. 2, 2014, by Brown et al.; U.S. Provisional Patent Application Ser. No. 62/020,177 entitled "Methods for Marking Biopsy Location", filed on Jul. 2, 2014, by Brown.; U.S. Provisional Patent Application Ser. No. 62/020,240 entitled "System and Method for Navigating Within the Lung", filed on Jul. 2, 2014, by Brown et al.; U.S. Provisional Patent Application Ser. No. 62/020,238 entitled "Intelligent Display", filed on Jul. 2, 2014, by Kehat et al.; U.S. Provisional Patent Application Ser. No. 62/020,242 entitled "Unified Coordinate System for Multiple CT Scans of Patient Lungs", filed on Jul. 2, 2014, by Greenburg.; U.S. Provisional Patent Application Ser. No. 62/020,245 entitled "Alignment CT", filed on Jul. 2, 2014, by Klein et al.; U.S. Provisional Patent Application Ser. No. 62/020,250 entitled "Algorithm for Fluoroscopic Pose Estimation", filed on Jul. 2, 2014, by Merlet.; U.S. Provisional Patent Application Ser. No. 62/020,261 entitled "System and Method for Segmentation of Lung", filed on Jul. 2, 2014, by Markov et al.; U.S. Provisional Patent Application Ser. No. 62/020,258 entitled "Cone View—A Method of Providing Distance and Orientation Feedback While Navigating in 3D", filed on Jul. 2, 2014, by Lachmanovich et al.; and U.S. Provisional Patent Application Ser. No. 62/020,262 entitled "Dynamic 3D Lung Map View for Tool Navigation Inside the Lung", filed on Jul. 2, 2014, by Weingarten et al., the entire contents of all of which are hereby incorporated by reference.

Although embodiments have been described in detail with reference to the accompanying drawings for the purpose of illustration and description, it is to be understood that the inventive processes and apparatus are not to be construed as limited thereby. It will be apparent to those of ordinary skill in the art that various modifications to the foregoing embodiments may be made without departing from the scope of the disclosure.

What is claimed is:

1. A system for detecting a trachea of a patient, comprising:
- a processor; and
- a memory, including instructions stored thereon, which, when executed by the processor cause the system to:
  - obtain a 3D model of a patient;
  - generate a plurality of slice images of the 3D model along an axial direction;
  - associate a connected component in a current slice image of the plurality of slice images with a corresponding connected component in a previous slice image of the plurality of slice images based on a connectivity criterion; and
  - identify each connected component in the current slice image associated with the connected component in the previous slice image as the trachea based on a length of the connected component.

2. The system according to claim **1**, wherein the instructions, when executed by the processor, cause the system to identify each connected component in each slice image of the plurality of slice images.

3. The system according to claim **1**, wherein the 3D model is based on image data obtained by an imaging device using a tomographic technique, radiography, a tomogram produced by a computerized axial tomography scan, magnetic resonance imaging, ultrasonography, contrast imaging, fluoroscopy, nuclear scans, or positron emission tomography.

4. The system according to claim **1**, wherein the instructions, when executed by the processor, cause the system to finalize an active object in the previous slice image.

5. The system according to claim **4**, wherein finalizing of the active object in the previous slice image is based on an association parameter.

6. The system according to claim **5**, wherein the association parameter is an area ratio calculated by dividing an area of the connected component in the current slice image by an area of the corresponding connected component in the previous slice image.

7. The system according to claim **5**, wherein the association parameter is a ratio between a number of coordinates of the connected component in the current slice image, which match coordinates of a corresponding active object in the previous slice image, and a number of non-matching coordinates of the connected component in the current slice image.

8. The system according to claim **5**, wherein the instructions, when executed by the processor, cause the system to remove a label of a corresponding active object in the previous slice image as an active object when the association parameter is greater than a predetermined value.

9. The system according to claim **8**, wherein the instructions, when executed by the processor, cause the system to remove the label of the connected component in the current slice image as an active object when the association parameter is greater than the predetermined value.

10. The system according to claim **5**, wherein the instructions, when executed by the processor, cause the system to label the connected component in the current slice image as an active object when the association parameter is greater than or equal to a first predetermined value and less than or equal to a second predetermined value.

11. The system according to claim 1, wherein the instructions, when executed by the processor, cause the system to calculate a length of a finalized active object.

12. The system according to claim 11, wherein the instructions, when executed by the processor, cause the system to calculate the length of the finalized active object by multiplying a number of the plurality of slice images including the finalized active object minus one and a distance between each slice image.

13. The system according to claim 11, wherein, when the length of the finalized active object is greater than or equal to 70 mm, the instructions, when executed by the processor, cause the system to indicate that the trachea is identified.

14. The system according to claim 11, wherein, when the length of the finalized active object is greater than or equal to 30 mm but less than 70 mm, the instructions, when executed by the processor, cause the system to indicate that the trachea is potentially identified.

15. The system according to claim 11, wherein, when the length of the finalized active object is less than 30 mm, the instructions, when executed by the processor, cause the system to indicate that the trachea has not been identified.

16. A system for detecting a trachea of a patient, comprising:
- a processor; and
- a memory, including instructions stored thereon, which, when executed by the processor cause the system to:
  - obtain a 3D model of a patient;
  - generate a plurality of slice images of the 3D model along an axial direction;
  - label a connected component in a top slice image of the plurality of slice images as an active object;
  - associate the connected component in a current slice image of the plurality of slice images with a corresponding connected component in a previous slice image of the plurality of slice images based on a connectivity criterion; and
  - label each connected component in the current slice image associated with a connected component in the previous slice image as the active object.

17. The system according to claim 16, wherein a connected component in the current slice image is associated with the corresponding connected component in the previous slice image when at least one of:
- coordinates of a pixel in the connected component in the current slice image matches coordinates of a pixel in the corresponding connected component in the previous slice image;
- a difference between a center of mass of the connected component in the current slice image and a center of mass of the corresponding connected component in the previous slice image is less than a predetermined value; or
- a difference between an area of the connected component in the current slice image and an area of the corresponding connected component in the previous slice image is less than a predetermined value.

18. The system according to claim 16, wherein the instructions, when executed by the processor, cause the system to identify the active object as the trachea based on a length of the active object.

19. A system for detecting a trachea of a patient, comprising:
- a processor; and
- a memory, including instructions stored thereon, which, when executed by the processor cause the system to:
  - obtain a 3D model of a patient;
  - generate a plurality of slice images of the 3D model along an axial direction;
  - label a connected component in a top slice image of the plurality of slice images as an active object;
  - associate the connected component in a current slice image of the plurality of slice images with a corresponding connected component in a previous slice image of the plurality of slice images based on a connectivity criterion; and
  - identify the active object as the trachea based on a length of the active object.

20. The system according to claim 19, wherein a connected component in the current slice image is associated with the corresponding connected component in the previous slice image when at least one of:
- coordinates of a pixel in the connected component in the current slice image matches coordinates of a pixel in the corresponding connected component in the previous slice image;
- a difference between a center of mass of the connected component in the current slice image and a center of mass of the corresponding connected component in the previous slice image is less than a predetermined value; or
- a difference between an area of the connected component in the current slice image and an area of the corresponding connected component in the previous slice image is less than a predetermined value.

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